Original Research Article

Seasonal fluctuation, diversity~~,~~ and composition of plankton communities in the Ganga River

Abstract: Plankton play~~s~~ a significant role in aquatic ecosystems by contributing to primary production, which supports fisheries and other vital features of ecosystems. The study was conducted for a period of one year in selected sites of the Ganga River, *i.e.*, Haridwar (Bhadrabad) site A1, Bijnor (Balawali) site A2, and Muzaffarnagar (Bairaj Ganga bridge) site A3. At site A1, phytoplankton ~~and zooplankton~~ were ~~found in the composition~~composed of Bacillariphyceae (65%) > Chlorophyceae (14%) > Cynophyceae (14%) > Ulvophyceae (7%), and zooplankton ~~and~~ were from Protozoa (80%) > Cladocera (20%). At site A2, the phytoplankton composition ~~was~~ were Bacillariphyceae (79%) > Chlorophyceae (7%) > Cynophyceae (7%) > Ulvophyceae (7%), and zooplankton were Protozoa (80%) > Rotifera (20%). At site A3 the phytoplankton composition changed to Bacillariphyceae (70%) > Chlorophyceae (18%) > Cynophyceae (12%) and Protozoa (60%) > Rotifera (40%). Simpson diversity index (D) value for phytoplankton shows the highest diversity at site A1 (D= 0.58), and for zooplankton, the value of D ~~was~~ with the highest diversity at site A3 was (0.53). The mean density of plankton at sites A1, A2, and A3 ~~was~~ were 2059, 2959, and 3304 Individual/L, respectively. Only dissolved oxygen in physico-chemical parameters showed a positive correlation ~~with plankton~~; ~~with~~ other~~s~~ parameters~~,~~ showed a negative correlation with plankton density~~was seen~~.

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Keywords: Simpson diversity, freshwater, density, zooplankton, phytoplankton

Introduction

The most challenging task in ecology has been understanding the mechanisms that ~~cause~~ induce changes in biological communities' species richness and composition. Planktonic algae, the primary producers, are located at the bottom of the trophic pyramid ~~alongside~~ while zooplankton were at higher layers of the pyramid and higher aquatic animals such as finfish, shellfish at the top.~~, and zooplankton.~~ In addition to its biological variety, phytoplankton play~~s~~ a significant role in aquatic ecosystems by contributing to primary production, which supports fisheries and other

vital features of ecosystems [1]**.** A rising number of studies are being conducted on developing large-scale river plankton [2, 3]. Compared to phytoplankton, zooplankton found in rivers receives less scientific attention. The stability of zooplankton in any aquatic body ~~of water~~ is profoundly important because they represent an important and sometimes unique food source for fish and many aquatic vertebrates [4]. Large, slow flowing rivers and still bodies of water are frequently the only locations where well-developed phytoplankton communities may be found~~, according to~~ [5].

In contrast, higher flow rates can upset the phytoplankton structure. Plankton variety responds swiftly to changes in the aquatic environment, generally changes in water quality parameters, and reacts ~~fast~~ rapidly to pollution. Several planktonic species have been bioindicators [6, 7]. They are also essential for the biogeochemical cycles of several vital elements, including methanogenesis, nitrification, and the carbon cycle, and these cycles lead to primary production and recycling. ~~Because~~ since the biological communities can be considered as the representative of the environmental conditions, biological evaluation is a good ~~substitute~~ indicator ~~for grading~~of the ecological quality of aquatic systems. Several recent studies on physico-chemical parameters and plankton community of rivers have been conducted on the Yamuna River [8], the Ganga River and its tributaries [9], the Sutlej River [10], and Jhelum River [11]. This study aimed to elucidate the changes in the composition of phytoplankton and zooplankton, their density, and their relationships with different physico-chemical parameters.

Materials and Methods

~~The~~ This study ~~lasted~~ was conducted for a twelve months period, from March 2019 to February 2020. ~~Depending upon the survey of the present investigation, t~~Three sampling sites were selected in both rivers. In the Ganga river, three sites from each district were selected~~,~~: *viz*: Haridwar (Bhadrabad) site A1, Bijnor (Balawali) site A2, and Muzaffarnagar (Bairaj Ganga bridge) site A3~~, were selected~~.

List 1 : Geographical locations of the sampling sites

Ganga river site	**A1**	**A2**	**A3**
Locations name	Bhadrabad	Balawali	Bairaj Ganga bridge

Map Location	29°55'15.1"N 78°04'42.2"E	29°38'07.0"N 78°06'21.7"E	29°22'26.1"N 78°02'03.5"E

Water samples were taken monthly from each sampling station ~~once a month~~ to investigate the water quality parameters. Following standard procedure, we measured the sample site's electrical conductivity, pH, dissolved oxygen, free CO_2, and water temperature [12]. Plankton samples were collected by filtering 100 L of the river water (through a plankton net of bolting silk number 25). The sieved samples were transferred to the sampling bottles of 20 ml and preserved in 4% formalin and lugol's solution to ensure absolute preservation [12]. Phytoplankton was identified under 10X and zooplankton under 40X objective lenses of the compound microscope (Olympus). Plankton were counted with the help of a Sedgewick Rafter counting cell of 1 ml capacity. Identification and categorization of phytoplankton and zooplankton was done using the standard taxonomic keys of [13,14,15]. Karl Pearson's correlation coefficient was ~~performed~~ measured using Microsoft Excel 2007 to determine the relationship among the various physico-chemical attributes.

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Simpson's Diversity Index (D) measures diversity by considering the number of species present and each species' relative abundance.

The formula to calculate Simpson's Diversity Index (D) is

$$D = 1 - \left[\frac{\Sigma\, n(n-1)}{N\,(N-1)} \right]$$

Where

n = the total number of organisms of a particular species

N = the total number of organisms of all species

Results and Discussion

Monitoring the physico-chemical parameters to investigate how they affect the distribution of different ~~biodiversity~~ biological components in freshwater ecosystems is crucial. The observed physico-chemical parameters from three different locations were DO (mg/l) recorded lowest at 7.4 and highest at 10.4, free carbon dioxide (mg/l) varied between 1.3 to 4.5, Water temperature (ºC)

between 13.1 to 20.1, pH between 7.2 to 7.9, and electrical conductivity (µS/cm) ranged between 122 to 189 during the entire study period. Higher dissolved oxygen values increase the photosynthetic rate of plankton and, hence, its density [16,17]. Phytoplankton use carbon dioxide and sunlight to make their food. The temperature range is significant because it impacts various metabolic processes in aquatic species [18]. Additionally, it safeguards aquatic life and modifies a stream's ecological health [19]. Alkaline water promotes high primary productivity [20]. EC is a measure of the ability of water to pass electrical flow. Higher levels of total dissolved solids can often indicate pollution by an extraneous source [21]. [22] have reported the influence of various ranges of hydrobiological parameters on the density and composition of plankton. Monthly variation in plankton density and mean density of the Ganga River are presented in Table 1.

In Ganga river at site A1 14 species of Phytoplankton ~~containing~~ included Chlorophyceae (*Spirogyra sp.* and *Zygnema sp.*), Cynophyceae (*Phormedium sp.* and *Oscillatoria sp.*), Bacillariphyceae (*Asterionella sp., Navicula sp., Caloneis sp., Cymbella sp., Diatoma sp., Stauroneis sp., Nitzchia sp., Fragilaria sp., Hantzchia sp.*) and Ulvophyceae (*Cladophora sp.)* were found during the study period. The presence and absence of phytoplankton and zooplankton are shown in Tables 2 & 3, respectively. The highest abundance of ~~group~~ Bacillariphyceae and a minimum of Ulvophyceae was observed at site A1. The order of ~~occurrence of~~ phytoplankton occurrence was Bacillariphyceae (65%) > Chlorophyceae (14%) > Cynophyceae (14%) > Ulvophyceae (7%). At site A1, two zooplankton groups with five species were observed during the study period ~~–~~ : Protozoa (80%) (*Astasia sp., Colpoda sp., Trachelophyllum sp., Loxodes sp.*) and Cladocera (20%) (*Daphnia sp.*). Protozoa were the dominant group found at site A1. The mean concentration at site A1 was 2059 Individual/L. Plankton production was positively correlated with DO and negatively correlated with free CO_2, Temperature, pH, and Electrical conductivity.

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At site A2, 14 species of Phytoplankton ~~containing~~ included Chlorophyceae (*Spirogyra sp.*), Cynophyceae (*Phormedium sp.*), Bacillariphyceae (*Cocconeis sp., Navicula sp., Caloneis sp., Cymbella sp., Diatoma sp., Stauroneis sp., Nitzchia sp., Fragilaria sp., Diploneis sp. Synedra sp. Achnanthes sp.*) and Ulvophyceae (*Cladophora sp.*) were found during the study period. The presence and absence of phytoplankton and zooplankton are shown in Tables 4 & 5, respectively. The highest abundance of ~~group~~ Bacillariphyceae and a minimum of Ulvophyceae was observed at site A2. The order of occurrence of phytoplankton was Bacillariphyceae (79%) > Chlorophyceae

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(7%) > Cynophyceae (7%) > Ulvophyceae (7%). At site A2, 2 zooplankton groups with five species were observed during the study period~~.~~: Protozoa (80%) (*Amoeba sp.*, *Colpoda sp.*, *Actinophrys sp*. and *Loxodes sp.*) and Rotifera (20%) (*Trichotria sp.*). Protozoa were the dominant group found at site A2. The mean ~~concentration~~ density at site A1 was 2959 Individual/L. Plankton production positively correlated with DO and negatively correlated with free CO_2, Temperature, pH, and Electrical conductivity.

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At site A3, 17 species of Phytoplankton ~~containing~~ included Chlorophyceae (*Spirogyra sp.*, *Closteriopsis sp. and Pediastrum sp.*), Cynophyceae (*Phormedium sp.* and *Spirulina sp.*) and Bacillariphyceae (*Cyclotella sp., Frustulia sp., Navicula sp., Caloneis sp., Cymbella sp., Diatoma sp., Stauroneis sp., Nitzchia sp., Fragilaria sp., Achnanthes sp., Cocconeis sp., and Diatomella sp*.) were found during the study period. The presence and absence of phytoplankton and zooplankton are shown in Tables 6 & 7, respectively. The highest abundance of group Bacillariphyceae and a minimum of Cynophyceae was observed at site A3. The order of ~~occurrence of~~ phytoplankton occurrence was Bacillariphyceae (70%) > Chlorophyceae (18%) > Cynophyceae (12%). At site A3, 2~~,~~ zooplankton groups with six species were observed during the study period~~.~~: Protozoa (60%) (*Amoeba sp., Colpoda sp., Astasia sp. and Trachelophyllum sp.*) and Rotifera (40%) (*Dicranophous sp.* and *Testudinella sp.*). Protozoa were the dominant group found at site A2. The mean ~~concentration~~ density at site A3 was 3304 Individuals/L. We observed plankton production, which was found to have a positive correlation with DO and a negative correlation with free CO_2, temperature, pH, and electrical conductivity.

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The Simpson diversity index (D) value for phytoplankton at site A1 (D= 0.58), ~~at site~~ A2 (0.40), and ~~site~~ A3 (0.49) shows that the highest diversity of phytoplankton was at site A1 and lowest at site A2. For zooplankton, the value of D at site A1 (D= 0.40), ~~at site~~ A2 (0.40), and ~~site~~ A3 (0.53) shows that the highest diversity for zooplankton was observed at site A1 and lowest at site A3.

The highest density in the Ganga River was observed during January and the lowest during the monsoon season, particularly in September, as presented in Table 1; similar results were obtained by [23,24]. In September, similar observations was reported from the Madurai water body [25]. This increase is due to favorable conditions returning after the monsoon season. The highest abundance of Bacillariophyceae has been observed at sites A1, A2, and A3; this is because, in contrast to other groups, Bacillariophyceae can adapt to a wide range of environmental

conditions. [26] claim that the Bacillariophyceae class is ~~global~~ cosmopolitan due to its excellent tolerance, adaptability, and ecological adaptation. [9] reported a total absence of rotifers during the monsoon season in the Ganga River, as seen in the present study at site A2. [27,28,29] among others, have also reported a similar trend. The maximum density of 4844 Individuals/L in Ganga River at the site in January, a similar trend was observed by [30]. In the present study, phytoplankton was found to be dominant over zooplankton. According to [31] zooplankton is one of the most significant connections influencing phytoplankton abundance and biomass in freshwater resources. Because zooplankton feeds on phytoplankton, a negative interaction between these two groups is predicted. The physico-chemical parameter affects the growth of algae in different seasons. Rainy seasons do not support algal growth; higher water flow restricts it. In the present study, 17 species were recorded from site A3, and diversity was also the highest from this region. The distribution, species density, species variety, and relative abundance of phytoplankton are indicators of a water body's ecological health [32]. Among ~~these groups of~~ zooplankton, Cladoceran and Copepods can be used as indicators of freshwater aquatic environments quality [33]. Abundance and dominance of protozoa were recorded from sites A1, A2, and A3, and the same has been reported in several water bodies [34,35,36,37]. The natural seasonality of the protozoa community was more or less interrupted by chemical water quality. This pattern is typical in many freshwater bodies like lakes, ponds, reservoirs, rivers~~,~~ or streams [38].

Table 1. Monthly variation in plankton density in Ganga River at different locations (Individual/L).

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	A1	A2	A3
March	2248	3466	4302
April	2516	3606	3826
May	2630	3480	3884
June	2792	3624	3458
July	1786	3048	2654
August	1148	1824	2280
September	930	1198	1262
October	1018	1224	1626
November	1968	2288	2808
December	2228	3642	4286
January	2864	4266	4844
February	2580	3842	4418

Mean	2059	2959	3304
SD±	695.89	1053.19	1164.16

Table 2. Phytoplankton composition observed at site A1 of Ganga River

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Chlorophyceae												
1. *Spirogyra* sp.	++	+	++	++	+	+	-	+	+	++	++	+
2. *Zygnema* sp.	-	-	+	+	+	-	-	-	+	++	++	-
Cynophyceae												
1. *Phormedium* sp.	++	+	++	++	+	-	-	-	-	+	++	++
2. *Oscillatoria sp.*	+	+	+	+	+	-	+	+	-	-	-	+
Bacillariphyceae												
1. *Asterionella* sp.	++	++	+	+	+	-	+	-	+	+	+	-
2. *Navicula* sp.	+	+	+	-	+	+	-	+	-	-	+	++
3. *Caloneis* sp.	++	+	++	++	+	+	+	+	++	++	++	+
4. *Cymbella* sp.	+	+	++	++	+	+	-	+	+	+	++	++
5. *Diatoma sp.*	+	++	++	++	+	+	+	+	+	+	++	++
6. *Stauroneis sp.*	+	+	-	-	-	-	-	-	-	+	+	+
7. *Nitzchia sp.*	+	+	++	++	+	+	+	+	++	++	++	++
8. *Fragilaria sp.*	++	+	+	+	+	-	-	-	-	-	++	+
9. *Hantzchia sp.*	+	++	++	++	+	+	+	-	-	+	+	-
Ulvophyceae												
1. *Cladophora sp*	+	++	++	+	-	-	-	+	+	-	+	-

Note: - (~~Absence~~Absent)
+ (~~Presence~~Present)
++ (~~Abundance~~Abundant)

Table 3. Zooplankton composition observed at site A1 of the Ganga River

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Cladocera												
1. *Daphnia sp.*	+	-	+	+	-	-	-	-	+	-	+	+
Protozoa												
1. *Astasia sp.*	++	+	++	+	++	+	-	-	-	+	++	++
2. *Colpoda sp.*	+	+	++	+	+	-	+	+	+	++	++	+

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3. Trachelophyllum sp.	+	+	-	-	-	-	-	-	-	-	+	+
4. Loxodes sp.	-	-	--	++	+	+	-	-	-	-	-	+

Note: - (Absence)
+ (Presence)
++ (Abundance)

Table 4. Phytoplankton composition observed at site A2 of the Ganga River

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Chlorophyceae												
1. *Spirogyra sp.*	++	++	+	++	+	+	-	+	+	+	++	++
Cynophyceae												
1. *Phormedium sp.*	+	+	+	+	+	-	-	-	-	+	+	++
Bacillariphyceae												
1. Cocconeis sp.	+	+	++	+	+	-	+	-	+	+	+	-
2. Navicula sp.	++	+	+	-	+	+	-	+	-	-	+	+
3. Caloneis sp.	++	+	+	+	+	-	-	+	+	-	+	++
4. Cymbella sp.	+	+	++	++	+	+	+	+	+	++	++	++
5. Diatoma sp.	++	+	+	++	++	+	+	+	++	+	+	+
6. Stauroneis sp.	+	+	+	+	+	+	+	+	+	-	-	+
7. Nitzchia sp.	-	+	+	-	-	-	-	+	++	++	+	-
8. Fragilaria sp.	+	+	+	-	-	-	-	-	-	++	+	++
9. Diploneis sp.	++	++	+	+	+	-	-	-	+	++	++	++
10. Synedra sp.	+	+	+	+	+	+	+	+	+	+	+	+
11. Achnanthes sp.	+	+	-	-	-	-	-	+	+	++	+	-
Ulvophyceae												
1. Cladophora sp.	+	+	+	+	-	-	-	+	+	-	+	-

Note: - (Absence)
+ (Presence)
++ (Abundance)

Table 5. Zooplankton composition observed at site A2 of the Ganga River

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Rotifera												
1. *Trichotria sp.*	+	-	+	+	-	-	-	-	+	-	++	+
Protozoa												

1. *Amoeba sp.*	+	++	+	++	+	+	-	-	-	+	++	+
2. *Colpoda sp.*	-	+	++	+	-	-	+	+	++	++	++	+
3. *Actinophrys sp.*	+	+	-	-	-	+	+	+	+	-	-	+
4. *Loxodes sp.*	-	-	-	+	+	-	-	-	-	-	+	+

Note: - (Absence)
+ (Presence)
++ (Abundance)

Table 6. Phytoplankton composition observed at site A3 of the Ganga River

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Chlorophyceae												
1. *Spirogyra sp.*	+	++	++	++	+	+	-	+	++	++	+	++
2. *Closteriopsis sp.*	+	+	-	-	-	+	+	+	+	-	-	-
3. *Pediastrum sp.*	+	+	+	+	-	-	-	-	-	-	++	+
Cynophyceae												
1. *Phormedium sp.*	+	+	+	+	+	-	-	-	-	+	+	+
2. *Spirulina sp.*	-	+	++	++	+	-	-	-	-	+	+	+
Bacillariphyceae												
1. *Cyclotella sp.*	+	+	+	+	+	-	+	-	+	++	++	
2. *Frustulia sp.*	+	+	+	-	+	+	-	+	-	-	+	+
3. *Caloneis sp.*	+	+	+	+	+	-	-	+	++	+	++	++
4. *Cymbella sp.*	++	++	+	++	+	+	+	+	+	+	+	+
5. *Diatoma sp.*	+	++	+	+	+	+	+	+	+	++	-	+
6. *Fragilaria sp.*	+	++	++	+	+	+	+	+	+	++	++	++
7. *Achnanthes sp.*	+	+	+	+	+	-	-	-	-	+	+	+
8. *Navicula sp.*	-	++	+	++	+	-	-	-	-	+	++	++
9. *Nitzchia sp.*	+	+	+	+	+	+	+	+	+	-	-	+
10. *Stauroneis sp.*	++	+	++	++	+	-	-	-	+	+	++	++
11. *Cocconeis sp.*	+	+	++	+	++	+	-	-	-	+	++	-
12. *Diatomella sp.*	-	-	+	+	+	-	-	-	+	+	-	+

Note: - (Absence)
+ (Presence)
++ (Abundance)

Table 7. Zooplankton composition observed at site A3 of the Ganga River

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Rotifera												

1. *Dicranophous sp.*	+	+	-	-	-	-	-	-	+	++	++	-
2. *Testudinella sp.*	-	+	+	-	-	+	+	-	-	-	-	+
Protozoa												
1. *Amoeba sp.*	+	+	+	+	+	+	-	-	-	+	+	+
2. *Colpoda sp.*	-	+	+	+	-	-	+	+	+	++	++	+
3. *Astasia sp.*	+	-	+	+	+	-	-	-	++	+	++	+
4. *Trachelophyllum sp.*	+	++	+	+	+	-	-	-	-	-	-	-

Note: - (Absence)
+ (Presence)
++ (Abundance)

Conclusion

In the present study, Bacillariphyceae emerged as the dominant group ~~in~~ of phytoplankton, and protozoa were the dominant group among zooplankton ~~from~~ among the studied stations. The mean plankton density at sites A1, A2, and A3 ~~was~~ were 2059, 2959, and 3304 individuals/L respectively, showing site A3 favors plankton growth. Simpson diversity index (D) value for phytoplankton shows the highest diversity at site A1 (D= 0.58). It shows that phytoplankton of a wide variety can flourish here, and the same has been observed for zooplankton at site A3 (0.53). It shows phytoplankton and zooplankton of a wide variety can flourish at each site. The basic information on the phytoplankton ~~photo~~ and zooplankton distribution and abundance would be helpful for further ecological assessment and monitoring of freshwater ecosystems.

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